Scintillator strip KLM detector (progress report)

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Motivation for a new KLM design

- The present RPC design for KLM demonstrated nice performance at Belle
- However, the efficiency decrease is observed due to high neutron background and large RPC dead time. The effect is not significant at barrel, but large for the endcap KLM.
- With SuperKEKB luminosity, it is still possible to use RPC at the barrel part with moderate modification: streamer/avalanche mode, faster gas mixture, shield in the innermost gap (Nakano san's talk at open meeting for proto-collaboration)

• Barrel : try to recover efficiency

efficiency at KEKB

Layer	Barrel	E fwd	E bwd
0	0.91	0.91	0.90
1	0.94	0.93	0.90
2	0.96	0.94	0.90
3	0.98	0.94	0.90
4	0.98	0.94	0.89
5	0.99	0.92	0.88
6	0.99	0.93	0.89
7	0.99	0.92	0.87
8	0.99	0.92	0.86
9	0.99	0.90	0.85
10	0.99	0.87	0.82
11	0.99	0.82	0.80
12	0.99	0.78	0.81
13	0.99	0.77	0.76
14	0.99	N/A	N/A

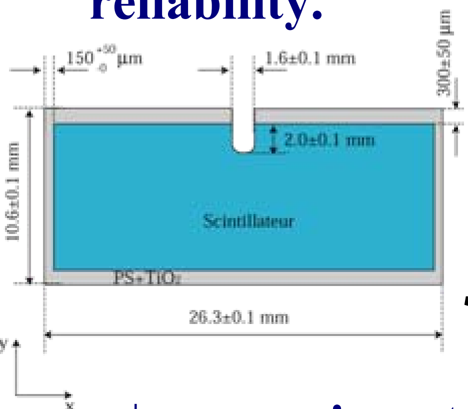
efficiency at SuperKEKB

Layer	Barrel	E fwd	E bwd
0	0.70	0.0	0.0
1	0.81	0.0	0.0
2	0.87	0.0	0.0
3	0.91	0.0	0.0
4	0.94	0.0	0.0
5	0.95	0.0	0.0
6	0.95	0.0	0.0
7	0.96	0.0	0.0
8	0.94	0.0	0.0
9	0.96	0.0	0.0
10	0.98	0.0	0.0
11	0.97	0.0	0.0
12	0.96	0.0	0.0
13	0.97	0.0	0.0
14	0.96	N/A	N/A

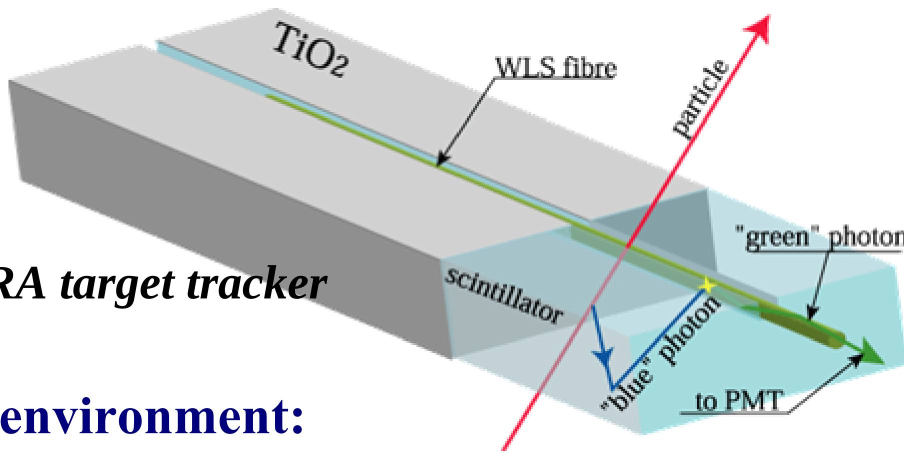
- However, the efficiency of endcap KLM becomes unacceptably low and new fast detector is required.

Scintillator option for endcap KLM

- **Plastic scintillator + WLS fiber read out successful in many neutrino experiments (MINOS, MINERva etc) and very popular in the new neutrino experiments (OPERA, T2K near detector), because of relatively low price, high reliability.**

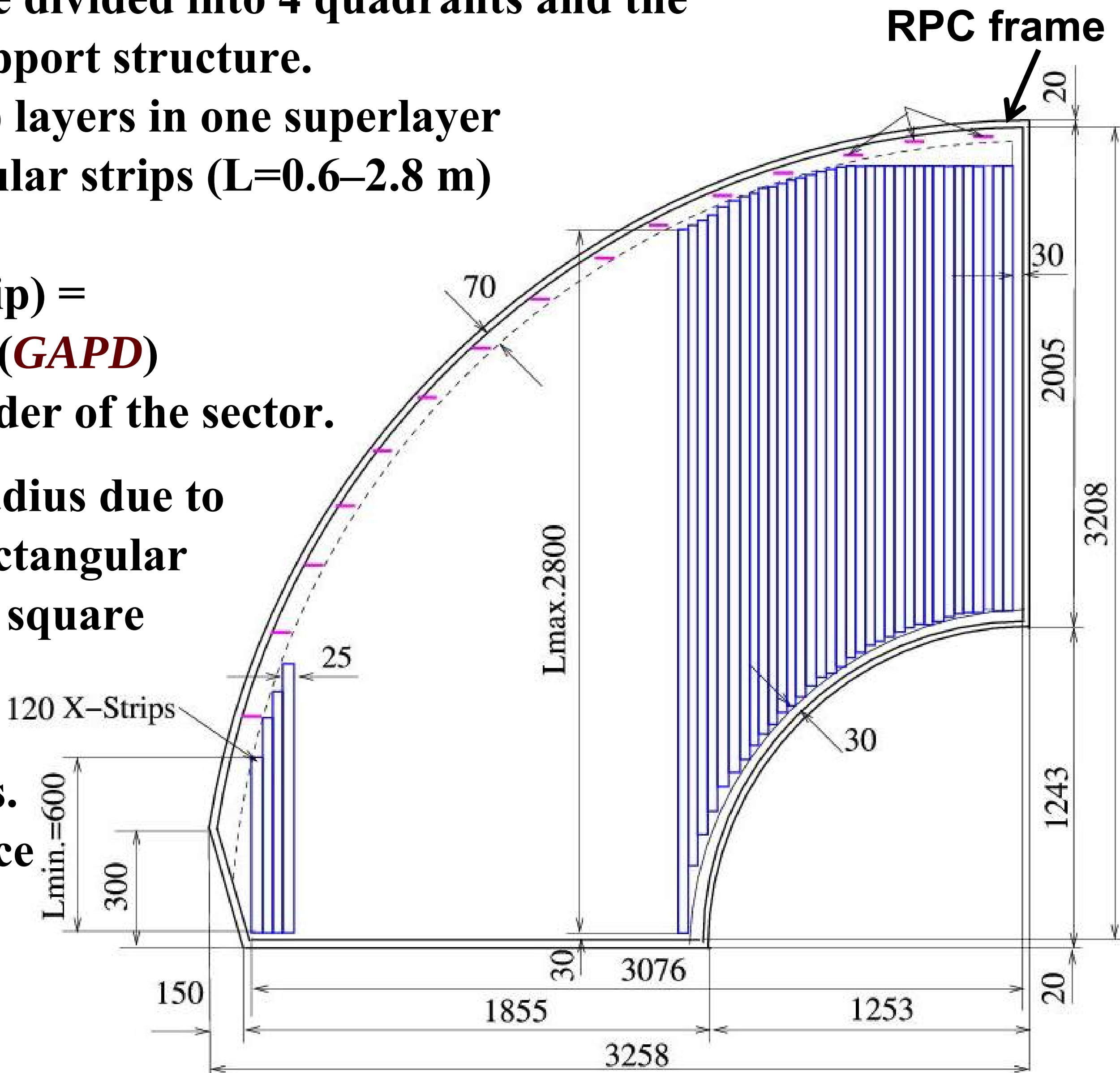


Scintillator strips for OPERA target tracker



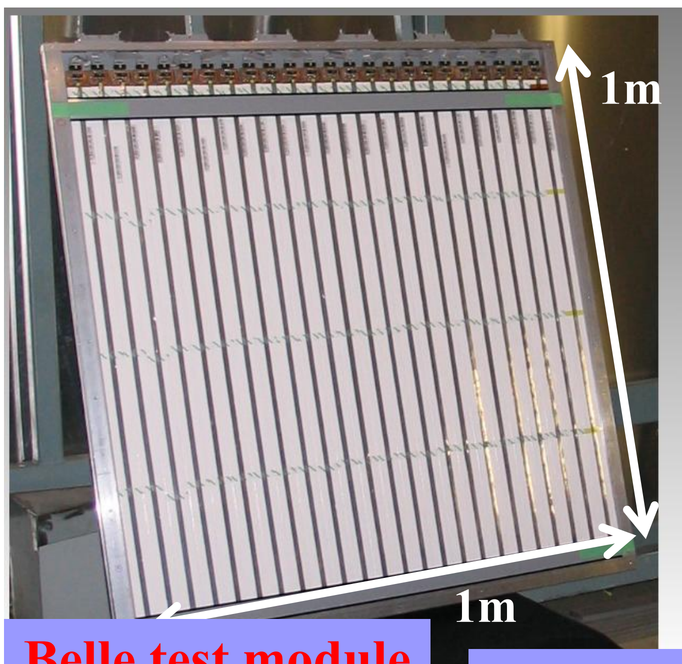
- **e^+e^- experiments has (slightly) different environment:**
  - **Higher occupancies**
  - **Radiation**
  - **(Huge) magnetic field**
  - **Limited space**
- **The extra requirements due to these new environments are ok for scintillator and WLS fiber;**
- **The choice of photodetector is the key question:**
  - **Photomulitpliers are not compact and poorly operates in the magnetic field.**
  - **New multipixel Si photo diodes operating in Geiger mode are tiny and insensitive to the magnetic field. The radiation hardness is checked to be sufficient.**

- **The geometry is fixed by the requirement to use the existing 4cm gaps in the iron magnet flux return yoke divided into 4 quadrants and the existing RPC frames as a support structure.**
- **Two independent (x and y) layers in one superlayer made of orthogonal rectangular strips (L=0.6–2.8 m) with WLS read out.**
- **Photodetector (one per strip) = photo diode in Geiger mode (*GAPD*) placed around the outer border of the sector.**
- **Dead zone around inner radius due to circle circumscribed with rectangular strips is ~ 0.2% of the sector square**
- **Outer dead zone is ~ 3% and may be reduced by adding few extra short strips. However the outer acceptance is not so much important.**

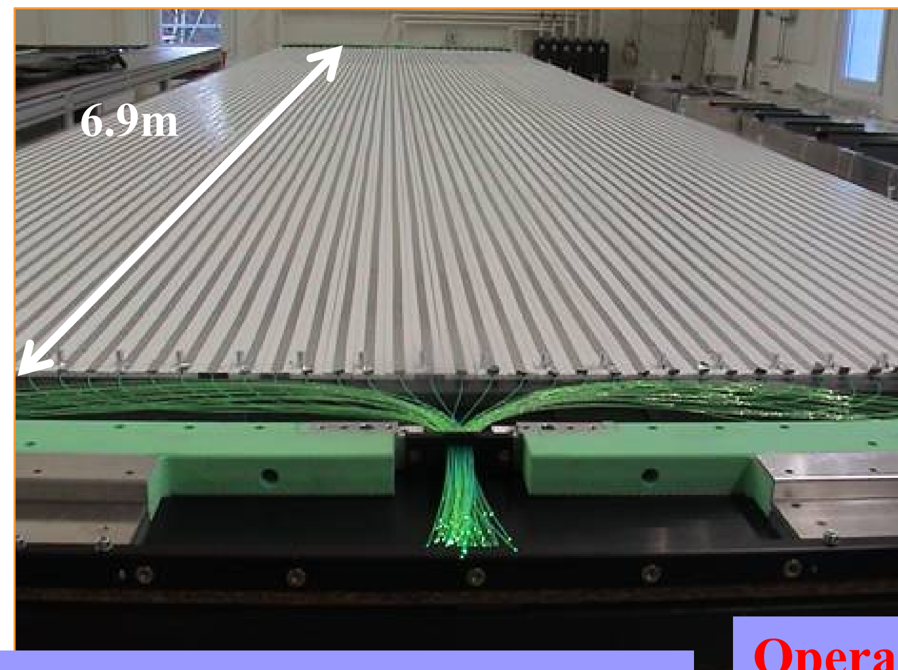


Producers

- **There are several producers for scintillator strips and photodetectors that meet our conditions and have an experience for mass production:**
- **Scintillator strips:**
  - **Kharkov (Ukraine)** ***produced scintillator strips for OPERA***
  - **Fermilab** ***produced scintillator strips for T2K***
- **Photodetectors:**
  - **CPTA (Russia)**
  - **Hamamtsu**
- **WLS fiber – Kurarai Y11 (no better option)**
- **Optical glue – St. Petersburg (Russia) or Bicron (expensive!)**



Belle test module



Opera

Extruded scintillator strips produced by Kharkov

We consider now two options of strip width:

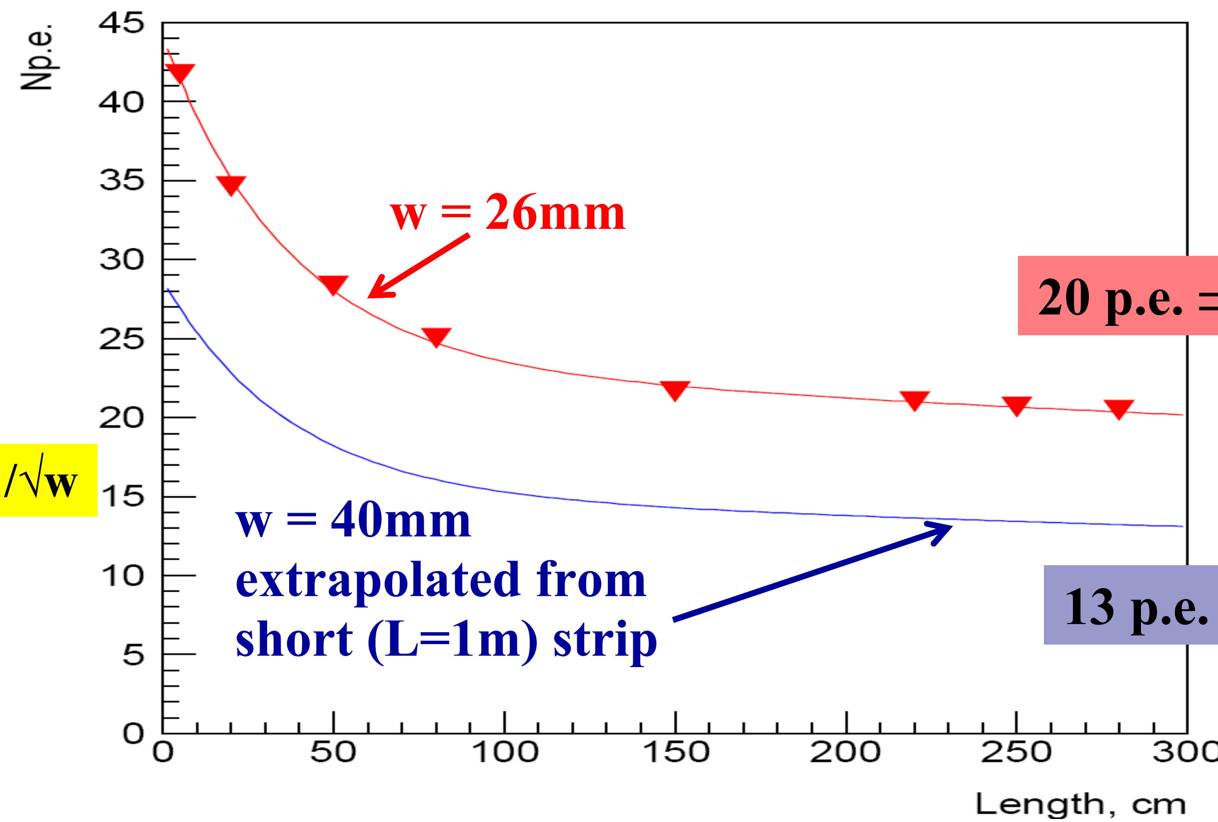
economic option (w=40mm) ≈ present RPC granularity (17k read out channels)

- **30% cheaper**

"improved" granularity (w=26mm) ≡ OPERA strips (27k read out channels)

Advantages:

- **30% more light;**
- **better muon ID**



N p.e. ~ 1/√w

Far end:

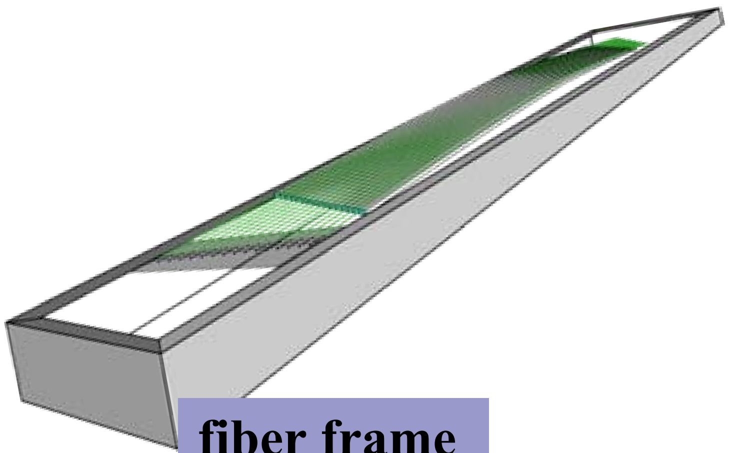
20 p.e. ⇒ 99.9% efficiency

13 p.e. ⇒ 98% efficiency

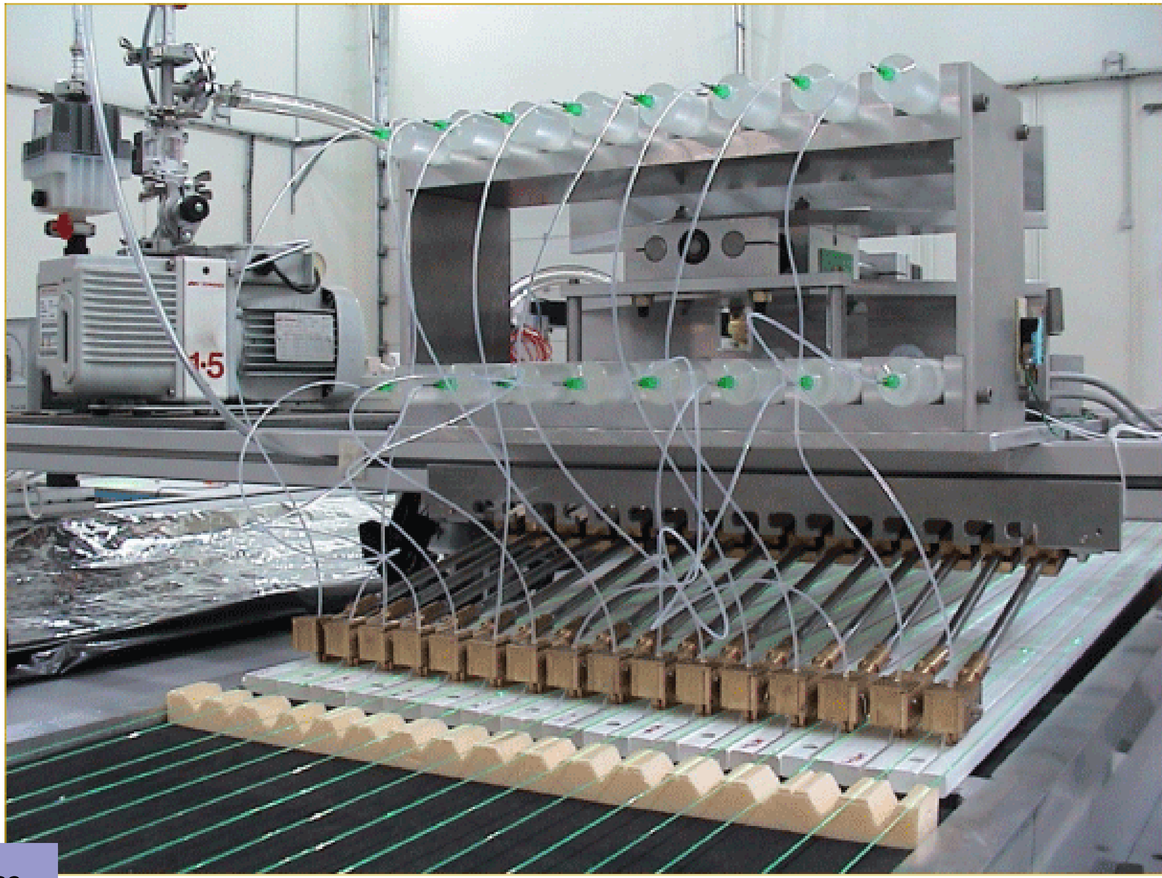
with 6 p.e. threshold

Manufacturing

- Manual fiber gluing is possible: this was done for the 200 strips of the test module by one person during 30 days. With getting more experience this can be done much faster. Estimated time for production of the whole system is 2 years.
- However we can take advantage of experience of neutrino experiments. Cooperation with Opera/T2K desirable?



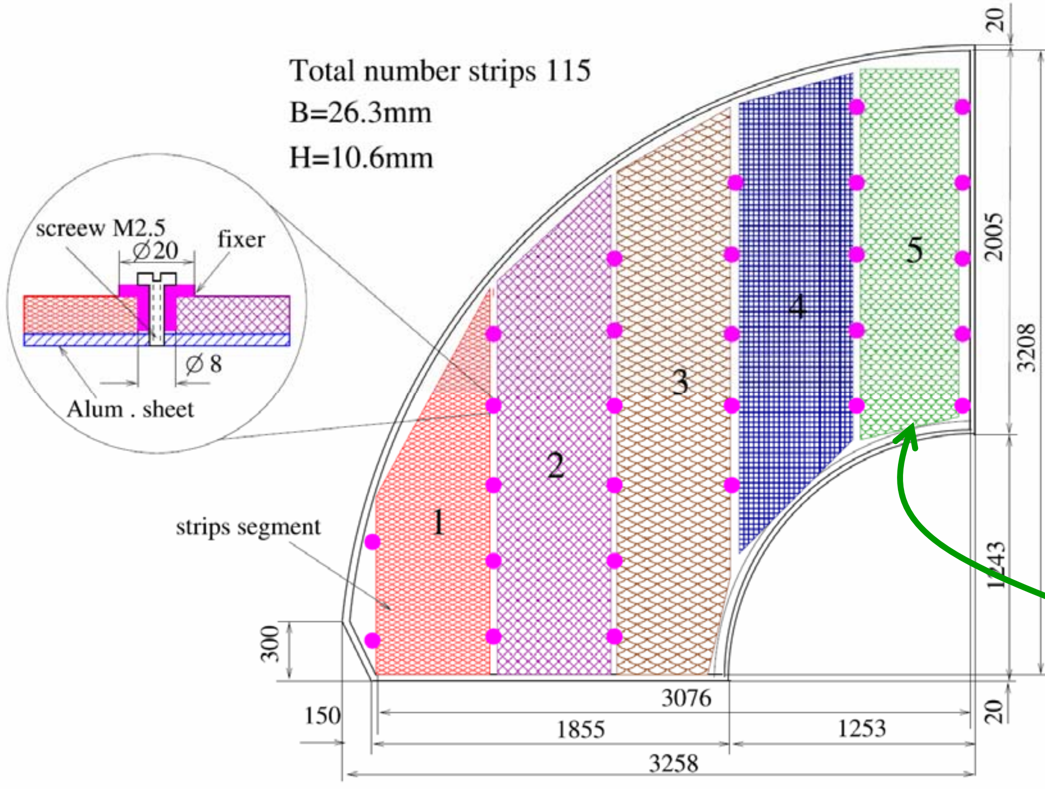
fiber frame



Opera fiber gluing system

Construction

We have to use the existing Al frames (their price is ~ 20% of the total KLM upgrade price)



115 strips/layer arranged into 5 segments: segment (23 strips bound together with a tape/scotch) is rigid enough and can be screwed to the Al sheet.

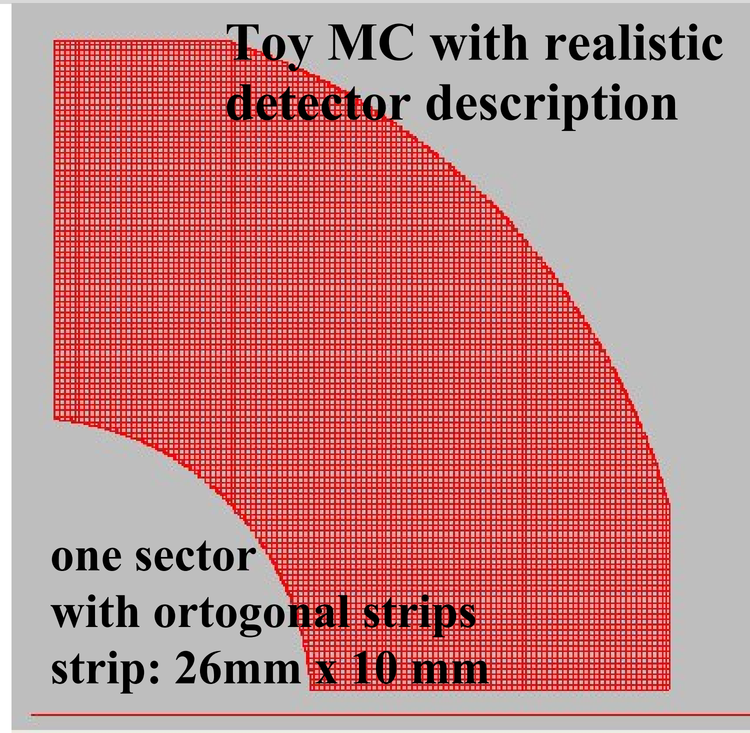
The dead zones are still << those of RPC.

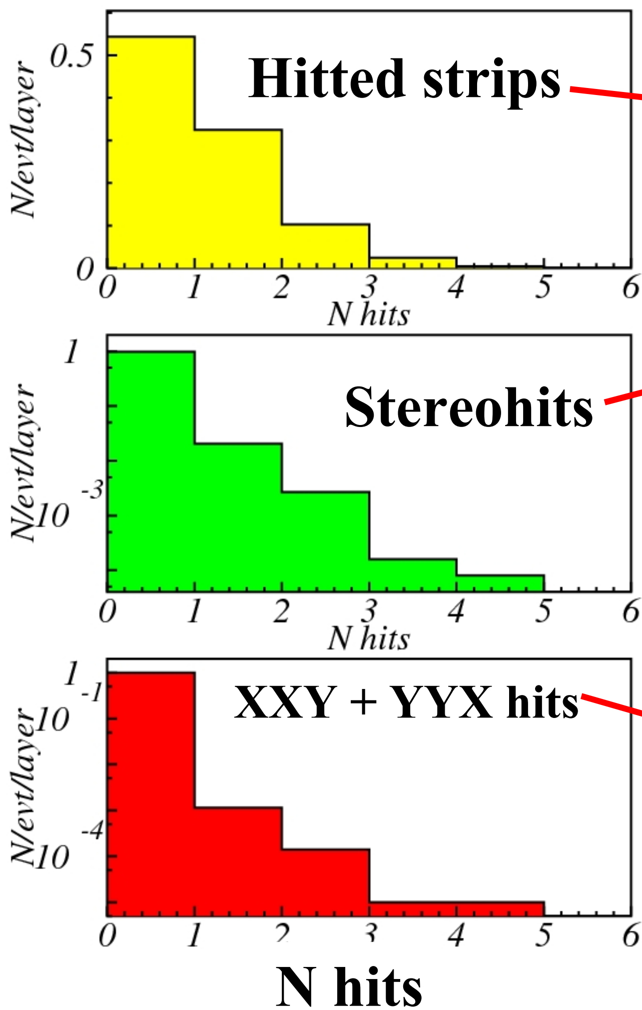
Physics performance

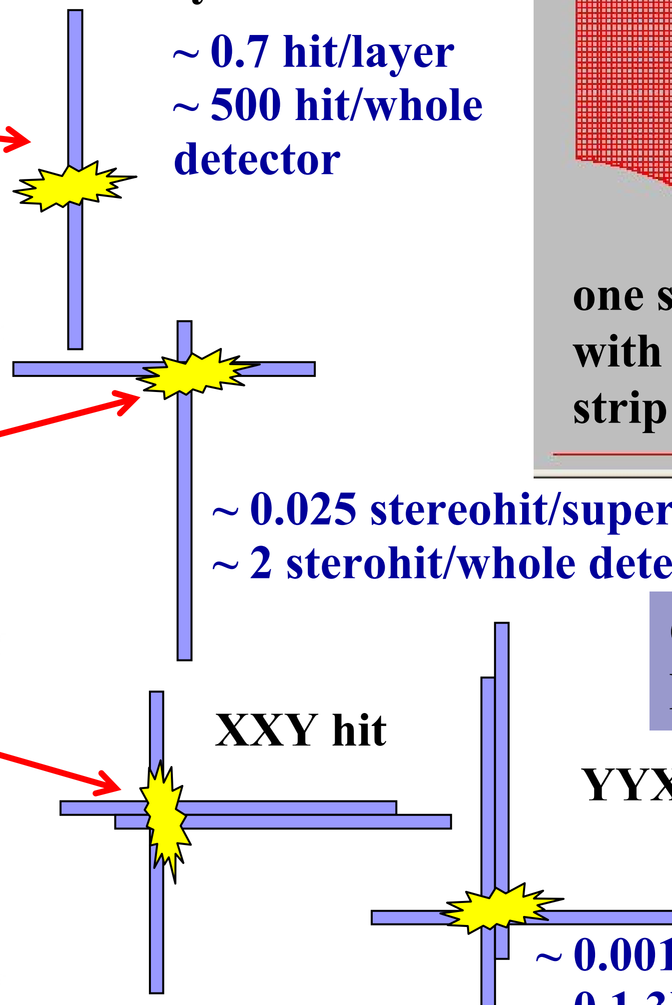
- **Scintillator detectors are more sensitive to neutrons (due to hydrogen in plastic). The tests in the KEKB tunnels show that neutron rate at scintillator strips is 5 Hz/cm^2 now; ⇒ 70 Hz/cm^2 at L=2×10^{35} /cm^2/s**
- **Background neutron can produce hits in one strip only (no correlated hits in x and y plane). This allows to have stereohit background rate smaller than at RPC in spite of increased single hit rate.**
- **Additional suppression is due to good time resolution (measured Strip+GAPD time resolution is ~1 ns), therefore x-y coincidence time can be cut at ±5ns.**
- **K_L detection ⇒ now two different tasks:**
  - **for reconstruction finals states including K_L (e.g. B → J/ψ (φ) K_L; D → K_Lπ): the time gate can be set at ±5ns from the expected (calculated time of flight using the known K_L momentum)**
  - **for K_L veto (B → τυ; B → hυυ): the time gate have to be as large as 50ns from the bunch crossing to accept all K_L momenta (for p~0.2GeV t~40ns)**
- **Muon identification should be better due to better spatial resolution (with 26mm strips) and higher MIP detection efficiency.**

Neutron background estimate

- Neutron hit rate: 100 Hz/cm^2
- Cross-talk between neighboring strips 1%
- Gate 50 ns
- Coincidence time between x and y hits 10 ns







~ 0.7 hit/layer
~ 500 hit/whole detector

~ 0.025 stereohit/superlayer
~ 2 sterohit/whole detector

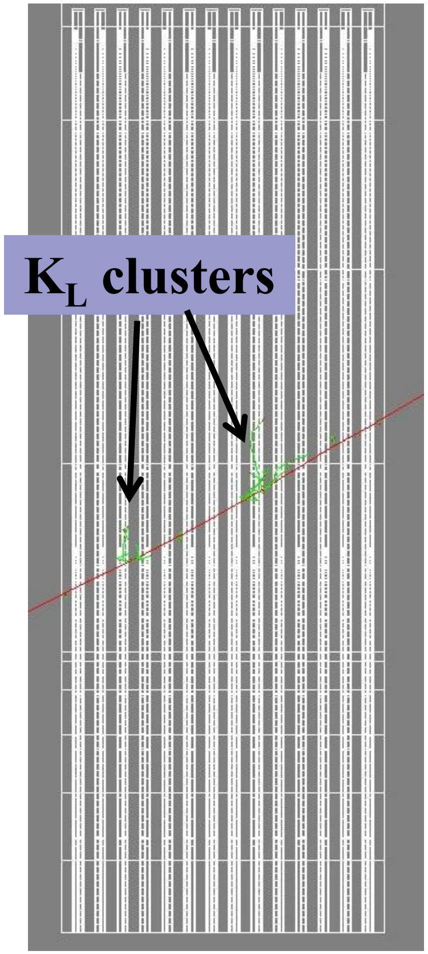
OK for K_L reconstruction
Not OK for K_L veto

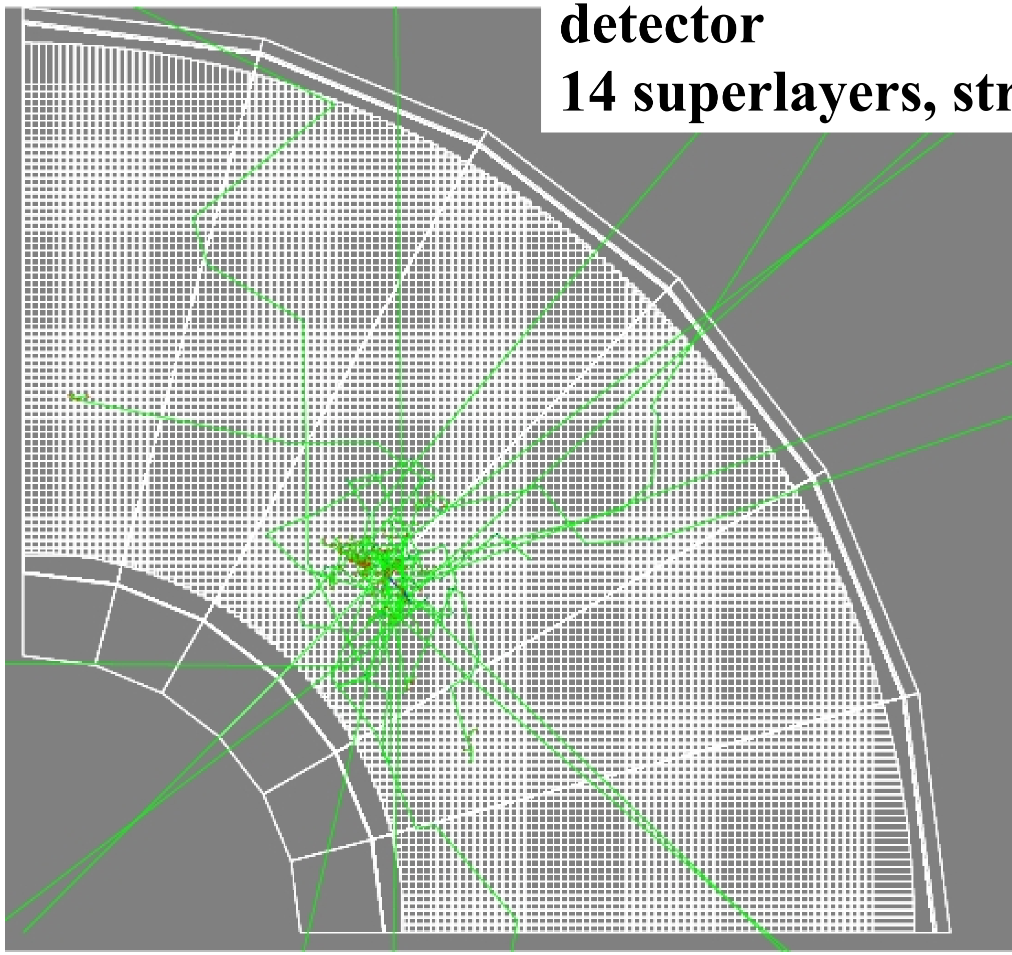
OK for K_L veto

~ 0.001 3hit-cluster/superlayer
~ 0.1 3hit-cluster/whole detector

Realistic G4-based prototype

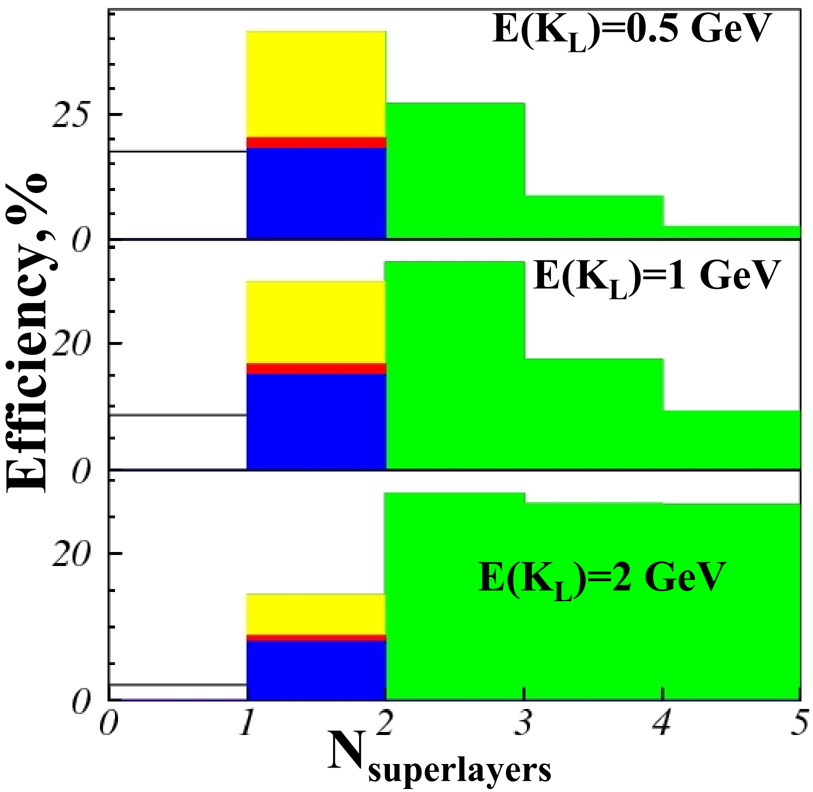
Geant4 standalone endcap KlM detector
14 superlayers, strip width 26mm





K_L efficiency study

- GEANT-4 simulation for standalone KLM detector; still no correction for
  - geometrical efficiency/ light collection efficiency
  - ECL

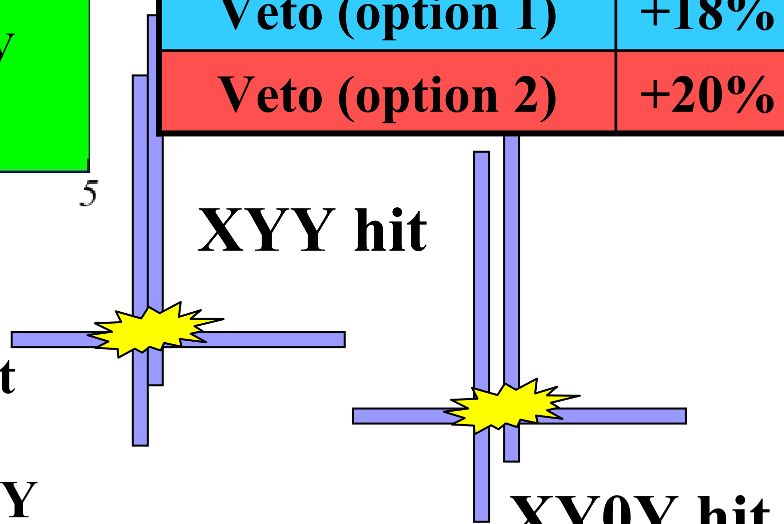


- Present algorithm: require two superlayers hits or ECL cluster + one superlayer

$E(K_L)$, GeV	0.5	1.0	2.0
Present efficiency	38%	59%	81%
Addition			
K_L reconstrution	+40%	+30%	+16%
Veto (option 1)	+18%	+15%	+9%
Veto (option 2)	+20%	+17%	+10%

Options to increase efficiency in the case of one superlayer hit

1. use 3hit-cluster XXY+XYY
2. use 3hit-cluster X0XY+XY0Y



Summary

- **Scintillator KLM design is OK for SuperBelle:**
  - **the efficiency of MIP detection can be kept at high level (>99% geometrical; thresholds: compromise between efficiency and neutron bg rate)**
  - **K_L reconstruction: The reconstruction efficiencies can be improved**
- **Radiation hardness of *GAPD* is sufficient for SuperBelle for endcap and barrel parts, but we do not have a large safety margin for $L=10^{36}$.**
- **The final optimization of the strip size is to be done with a full GEANT simulation of the whole SuperBelle detector (in progress now).**
- **The negations with producers started; Their products have similar characteristics, that are ok for us, and the prices from different producers are similar.**
- **The test with a real prototype in the KEKB tunnel allowed to measure neutron background rate and estimate the radiation hardness of GAPD in real conditions.**

Cost estimate for endcap KLM

Item		price	cost
Scintillator strips	28, 000 pc. (14,000 kg)	20 $/kg	280 k$
WLS fiber	56 km	1.4 $/km	80 k$
Photo-detectors CPTA	28, 000 pc.	20 $/pc.	560 k$
Optical glue	300 kg		30 k$
Electronics	28, 000 ch.	? $/ch.	? k$
Miscellaneous			70 k$
Transportation			40 k$
Total			1060 k$

* Cost estimate for electronics will be made after the electronics design
** Cost does not include electronics, labor and R&D
*** Changes in $ exchange rate can influence the cost